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THESIS

SHIPBUILDING INTEGRATION

by

Joanna M. Carter

December 2005

Thesis Advisor: Orin Marvel
Co-Advisor: John Gudas

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13. ABSTRACT (maximum 200 words)

The build cycle of a first in class combat ship takes about six years. During that timeframe, systems are being designed, installed, and tested, but, until the ship is in the water and tested at sea trials, it is not known if the ship is fully integrated and will actually work. As time progresses, integration problems become harder and more expensive to solve. Every time a new system is added or upgraded, there may be interference from another system that was not anticipated. It is important to test and verify each system, but there is limited time and resources to do so. By successfully planning and performing systems integration at the correct time of the acquisition cycle, it is possible to reduce the chance of system failure. This thesis explains and establishes a process for designing and building a fully integrated combat ship by first defining systems integration for the customer and the shipbuilder and explaining why performing systems integration is important.

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SHIPBUILDING INTEGRATION

Joanna M. Carter
Civilian, Northrop Grumman, Pascagoula, Mississippi
B.S., University of South Alabama, 1996

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Author: Joanna Carter

Approved by: Dr. Orin Marvel
Thesis Advisor

Dr. John Gudas
Co-Advisor

Dr. Frank Shoup
Director, Wayne E. Meyer Institute of Systems Engineering

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ABSTRACT

The build cycle of a first in class combat ship takes about six years. During that timeframe systems are being designed, installed and tested, but until the ship is in the water and tested at sea trials it is not known if the ship is fully integrated and will actually perform as it is designed to do. As time progresses integration problems become harder and more expensive to solve. Every time a new system is added or upgraded there may be interference from another system that was not anticipated. It is important to test and verify each system but there is limited time and resources to do so. By successfully planning and performing systems integration at the correct time of the acquisition cycle it is possible to reduce the chance of system failure. The objective of this thesis is to explain and establish the process of building a fully integrated combat ship.

To understand how to perform integration first we must define what it means to our customer, the Navy, and us, the shipbuilder. This is accomplished in the first chapter. The second chapter concentrates on why we need to perform system integration by explaining the history of the U.S. Navy's shipbuilding program and case studies of successful and not as successful integrated systems. The last chapter contains a list of concepts and ideas to implement into a combat ship design and build program to simplify shipbuilding integration.

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I. INTEGRATION CHARACTERIZATION

A. INTRODUCTION

Ships are essentially floating cities, and combat ships add the complexity of war fighting capabilities to their mission. Of all the equipment Congress purchases for the military, only ships are in the category of Capital equipment. This means that the equipment has a large dollar value and therefore special oversight. Shipbuilding continues to be a very labor-intensive industry that relies mainly on past performance and experience to measure progress to completion. As our systems become even more complex, the old "rules of thumb" for designing and building a successful working ship may not apply.

The build cycle of a first in class combat ship takes about six years. During that timeframe, systems are being designed, installed, and tested, but until the ship is in the water and tested at sea trials it is not known if the ship is fully integrated and will actually perform as designed. As time progresses integration problems become harder and more expensive to solve. Every time a new system is added or upgraded there may be interference from another system that was not anticipated. It is important to test and verify each system, but there is limited time and resources to do so. By successfully planning and performing systems integration at the correct time of the acquisition cycle, it is possible to reduce the chance of system failure. The objective of this thesis is to explain and establish the process of building a fully integrated combat ship.

To understand how to perform integration, first we must define what it means to our customer, the Navy, and us, the shipbuilder. This is accomplished in the first chapter. The second chapter concentrates on why we need to perform system integration by explaining the history of the U.S. Navy's shipbuilding program and case studies of successful and not as successful integrated systems. The last chapter contains concepts and ideas to implement into a combat ship design and build program to simplify shipbuilding integration.

To properly place systems integration into the acquisition cycle, the thesis begins with defining systems engineering.

B. DEFINING SYSTEMS ENGINEERING

Systems engineering is not a field that is as clear cut as many of the other engineering disciplines, but systems engineering is rather young compared to traditional engineering disciplines, such as civil, mechanical, and electrical engineering. It may be due to its age that it's hard to define systems engineering, but defining of a field of study that does not have any real tangible product will always be hard to explain to people, especially engineers. First, the paper will discuss the International Council on Systems Engineering's definition and then the Department of Defense's definition, and then compare the two explanations.

1. International Council on Systems Engineering Definition

The International Council on Systems Engineering has worked for years to create a concise definition of systems engineering. Founded in 1990, the "International Council on Systems Engineering is an international authoritative body promoting the application of an interdisciplinary approach and means to enable the realization of successful systems." ("A Consensus of the INCOSE Fellows," 2004) I find their definition to be very exact and understandable:

> Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:
>
> Operations
> Performance
> Test
> Manufacturing
> Cost and Schedule
> Training and Support
> Disposal

> Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE website, 2005)

By taking the definition and decomposing it we can see where integration fits into the systems engineering definition.

> Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. (INCOSE website, 2005)

This is the overall goal of systems engineering: to create a successful system; not just a system, but a successful one. That means looking and analyzing the customer's needs and requirements and ensuring that what the customer is asking for actually fits their needs. They could have stopped here, but then the definition would not have told us what systems engineers do.

> It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:
>
> Operations
>
> Performance
>
> Test
>
> Manufacturing
>
> Cost and Schedule
>
> Training and Support
>
> Disposal (INCOSE website, 2005)

The first part of the sentence explains how systems engineers take the customer requirements and break them into groups so that design engineers can design their part of the system. With the increasing complexity of system design, boundaries must be drawn for the work to be performed correctly. When the systems engineer breaks the system down into these workable chunks they pass along to the design engineer how the seven items listed need to be considered in the design. By doing this the design engineers can focus on their part of the problem and are not distracted by other parts of the problem. Requirements keep designers focused on the problem they have been given responsibility to solve.

> Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. (INCOSE website, 2005)

This part of the definition concentrates on integration. It is this part of the definition on which this thesis is focused. Once the system has been decomposed for design purposes to obtain a buildable and usable system it must be merged back together. This is the integration phase of the design process.

> Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs. (INCOSE website, 2005)

The last sentence is a wrap up of what was said in the first sentence, making note that systems engineering focuses on business and technical needs. The systems engineers are responsible for making certain that the customer receives what they need and can afford.

2. Department of Defense Definition

Because this paper is focused on building U.S. Navy ships we will explore the definition the Department of Defense has for systems engineering. It should be noted that the Department of Defense definition is created not for the builder of system, but the program managers and defense employees acquiring the system. From the Defense Acquisition Guidebook (2005):

> Systems engineering is the overarching process that a program team applies to transition from a stated capability need to an operationally effective and suitable system. Systems engineering encompasses the application of systems engineering processes across the acquisition life cycle (adapted to each and every phase) and is intended to be the integrating mechanism for balanced solutions addressing capability needs, design considerations and constraints, as well as limitations imposed by technology, budget,

> and schedule. The systems engineering processes are applied early in concept definition, and then continuously throughout the total life cycle. (Chap. 4.0)

As done previously with the International Council on Systems Engineering definition, we will separate and analyze the definition. The first sentence:

> Systems engineering is the overarching process that a program team applies to transition from a stated capability need to an operationally effective and suitable system. (Defense Acquisition Guidebook, 2005, Chap. 4.0)

What is being described is that a process is used to get from customer needs to a workable system. It's said in a different way, but the International Council on Systems Engineering definition covers this point. There is not the emphasis on providing the customer with what they need versus what they ask for with this definition. It is assumed that the "stated capability" has already been judged as achievable by the government.

> Systems engineering encompasses the application of systems engineering processes across the acquisition life cycle (adapted to each and every phase) and is intended to be the integrating mechanism for balanced solutions addressing capability needs, design considerations and constraints, as well as limitations imposed by technology, budget, and schedule. (Defense Acquisition Guidebook, 2005, Chap. 4.0)

Here is the point where integrating is mentioned in the definition. Department of Defense has a shorter list than the International Council on Systems Engineering, leaving out manufacturing, test, disposal, etc but essentially says that systems engineering should be used through out the entire acquisition life cycle which one could say includes those items left out of the Department of Defense definition. The Department of Defense states that systems engineering is the "mechanism" for how the parts are integrated for the overall system. This implies that systems integration is a part of systems engineering process and therefore not at the same level.

And then the last sentence: "The systems engineering processes are applied early in concept definition, and then continuously throughout the total life cycle," (Defense Acquisition Guidebook, 2005, Chap. 4.0) reemphasizing that systems engineering is to be used throughout the entire acquisition cycle.

3. Key Points of Systems Engineering Definitions

I chose to use two definitions for explaining systems engineering: the International Council on Systems Engineering definition because it is a very concise yet broad definition that concentrates on the system engineer designing and building the system, and the Department of Defense definition because the customer of United States Navy warships is the Department of Defense.

Table 1 summarizes the key points each definition makes about a three main topics.

KEY POINT	INTERNATIONAL COUNCIL ON SYSTEMS ENGINEERING	DEPARTMENT OF DEFENSE
Goal of SE	Create a successful system that meets technical and business customer needs.	Create an operationally effective and suitable system.
Timeframe	Concept to operation.	Throughout the entire acquisition cycle.
How System Integration is Addressed	Brings together people with different specialties.	Described as the "balancing mechanism."

Table 1: Key Points of Systems Engineering Definition (after INCOSE website, 2005 and Defense Acquisition Guidebook, 2005, Chap. 4.0)

The International Council on Systems Engineering has a broader focus on commercial applications, while the Department of Defense centers on products used by the military. For this reason the goals are different. The International Council on Systems Engineering's goal is to create a successful system, while the Department of Defense wants a system that is effective and suitable in the environment it was created to fight in. In the commercial world success is measured by profits, but in the Department of Defense world success is measured in the ability to save our soldier's lives and protect our country.

The timeframe is longer for the Department of Defense to include the disposal cycle because lifecycle issues are generally not as important in commercial applications as they are with the Department of Defense. Ships are normally kept in service for thirty years. Trying to lower the costs associated with operating ships is very important to the United States Navy.

Systems Integration is mentioned in both definitions, but with different explanations. The International Council on Systems Engineering concentrates more on the idea of bringing together different ideas and backgrounds to create a product. The International Council on Systems Engineering centers on a people oriented tasks. The Department of Defense uses integrating to mean how the product is balanced across cost, schedule, and performance. The definitions want the same outcome, but the Department of Defense centers on the program metrics of cost, schedule, and performance. Those items are important in the commercial world too, but those are constraints commercial firms always have to consider. The Department of Defense has been evolving from a time where the most important consideration was performance, then schedule, and cost was the least important. Now the Department of Defense faces more public scrutiny on how the defense budget is spent and must change the way their systems are procured. This is the reason for the different emphasizes in the definitions between the International Council on Systems Engineering and the Department of Defense.

4. Author's Synopsis of Systems Engineering Definition

My personal explanation and purpose of systems engineering is "to bring order to chaos." We have reached a period of time where products or systems are so complex that a small group of designers can no longer understand every part of the system. When the ability to understand every detail and make it whole with a manageable group of people was lost, systems engineering as a separate field of practice became necessary. For this reason it is my belief that it is not a question of whether systems engineering exists or not, but if it is good or bad systems engineering.

Systems engineering should not necessarily deliver to the customer what they initially request. There is an important distinction here in that just because the customer says they want a certain feature that feature may not be needed to achieve the overall goal of the system or it could be unrealistic for the amount of money and time that it would take the contractor to develop. It is the systems engineer's responsibility to educate the customer on these issues.

C. DEFINING SYSTEMS INTEGRATION

Systems engineering is the process that creates an environment in which the system can be designed. It provides the clear path forward to each design engineer. Systems integration is the part of that process that brings back together what has been separated out for design purposes. First the paper will discuss the Department of Defense's definition of systems integration and then explain what it means to the shipbuilder.

1. Department of Defense's Definition of Systems Integration

Systems integration is a part of systems engineering and systems engineering by Department of Defense rules is suppose to occur throughout the entire acquisition cycle. The Department of Defense places integration in the Life Cycle Management Framework in Figure 1 as the first part of the System Development and Demonstration Phase located between Milestone B and C.

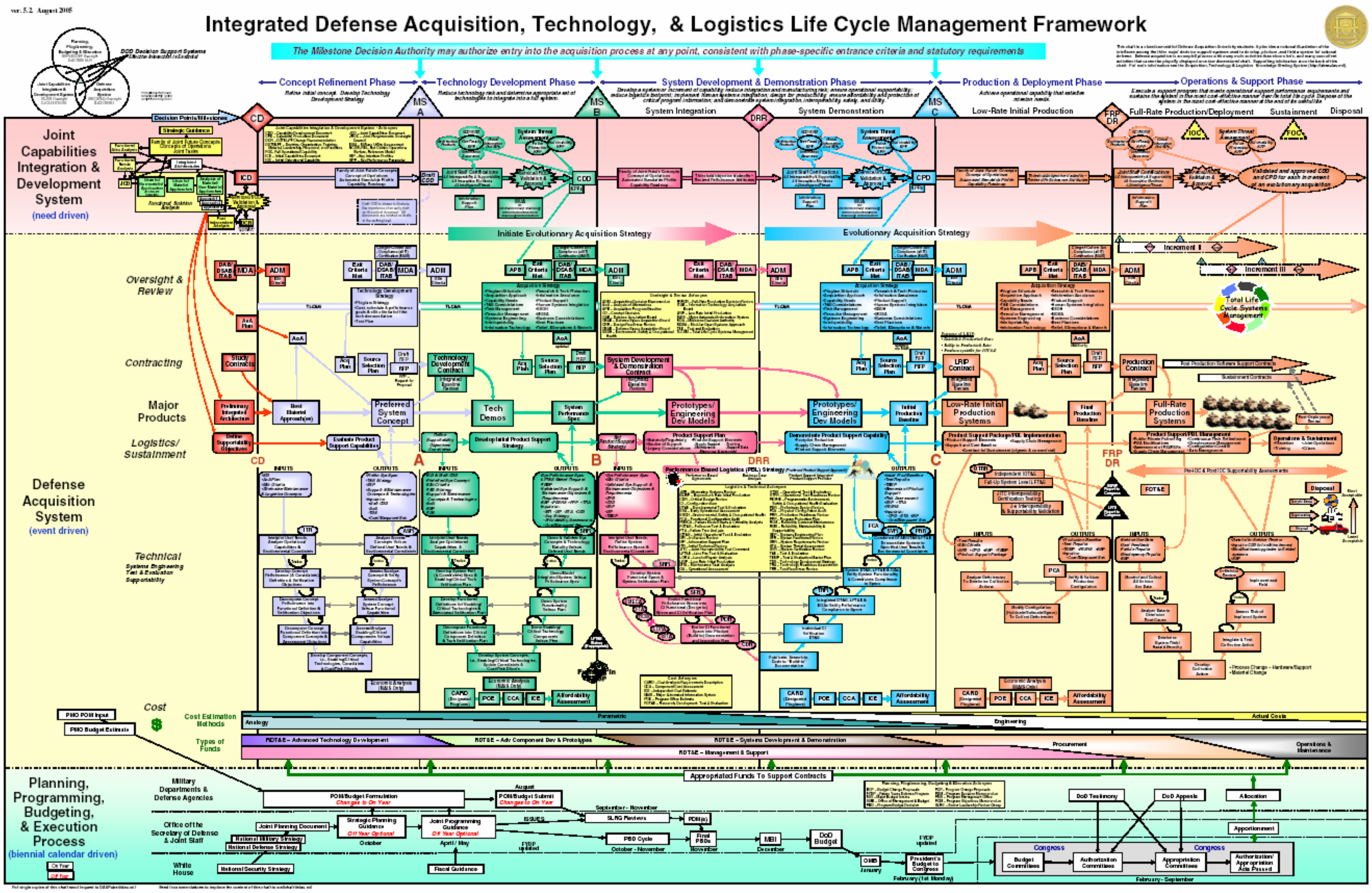

Figure 1. Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management Framework (from http://akss.dau.mil/dapc/index.html)

See Figure 2 for a simpler view of the phases and milestones. The figure is from 2003, but the phases have remained the same. This phase was added in October 2000. (Dillard, 2003, p. 33) In that phase are two sub phases, System Integration and System Demonstration.

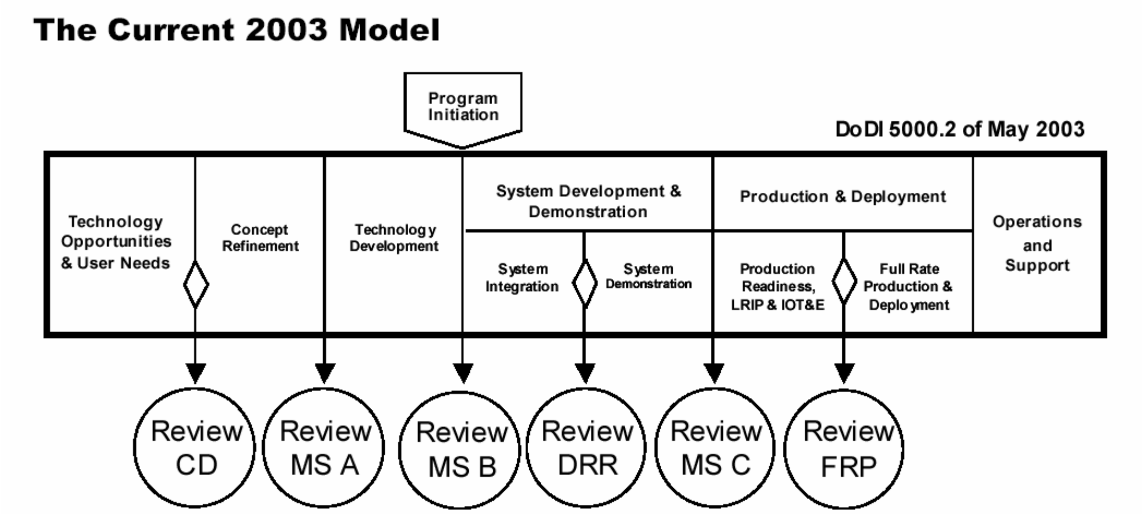

Figure 2. Simplified Defense Acquisition Management Framework (from Dillard, 2003, p. 36)

System Integration falls between Milestone B and Design Readiness Review (DRR). Milestone B marks the end of the Technology Development Phase. “The Technology Development Phase ends when the Milestone Decision Authority determines that technologies are sufficiently mature. This determination, along with the satisfaction of other statutory and regulatory requirements, supports program initiation.” (Defense Acquisition Guidebook, 2005, Chap. 2.2.1) This tells us that the concept design must be mature enough to proceed to being the System Integration sub phase. It is important to note here that what the Department of Defense considers as integration is not the same thing that the builder of the system would call integration. This statement will be expounded in Section 3, author’s synopsis of systems integration definition.

Figure 3 displays the model used by Department of Defense to display the tasks required for the phase. System Integration is the downward part of the "v" and System Demonstration is the upward part of the "v."

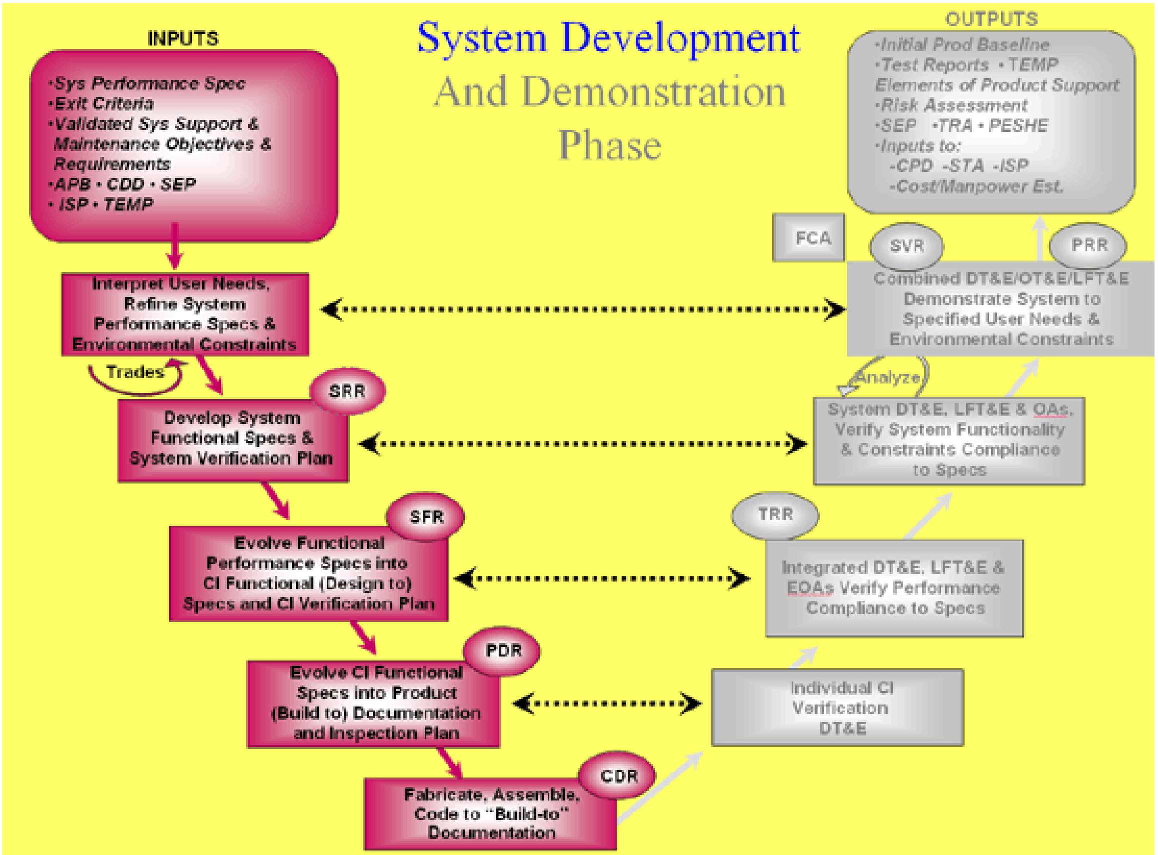

Figure 3. Department of Defense SDD Model (from Defense Acquisition Guidebook, 2005, Chap. 4.3.3.3)

To finish the System Integration sub phase is the DRR event. From the Defense Acquisition Guidebook:

> The Design Readiness Review during SDD provides an opportunity for mid-phase assessment of design maturity as evidenced by measures such as the number of subsystem and system design reviews successfully completed; the percentage of drawings completed; planned corrective actions to hardware/software deficiencies; adequate development testing; an assessment of environment, safety and occupational health risks; a completed failure modes and effects analysis; the identification of key system characteristics and critical manufacturing processes; an estimate of

> system reliability based on demonstrated reliability rates; etc. Successful completion of the Design Readiness Review ends System Integration and continues the SDD phase into the System Demonstration effort. MDAs may, consistent with the intent of this paragraph, determine the form and content of the review. (Defense Acquisition Guidebook, 2005, Chap. 3.7.4)

This means that before the system integration sub phase the concept design should be mature, but production does not begin until after the system integration sub phase. This places system integration for the Department of Defense between requirements development and production.

2. Systems Integration Sub Phase

In the Technology Development Phase the design engineers have taken their requirements provided by the system engineers and designed a product that meets those requirements. But in the System Integration sub phase the engineers gather together and review with each other various parts of the design. Dillard (2003) defines the task of the system integration phase "for the reduction of integration risk. The architecture is complete, now system integration is applied to demonstrated subsystems and components." (p. 33) The Defense Acquisition Guidebook (2005) describes the Systems Integration phase as follows:

> The System Integration work effort begins when the program manager has a technical solution for the system or increment of capability, but has not integrated the components and subsystems into a system. Through the use of systems engineering, the System Integration effort integrates components and subsystems, completes the detailed design, and reduces system level risk. The effort typically includes the demonstration of prototype articles or engineering development models. (Chap. 4.3.3.2)

The easiest way to explain this is to take an example.

A combat ship for the U.S. Navy has a performance requirement to have a maximum ship speed of 30 knots. First the system engineer splits and assigns the requirement to the naval architects, the power engineers, and control engineers if they expect to use software to control the equipment. The naval architects create a hull form that is capable of reaching 30 knots, the power engineers size the engine to provide enough power to go 30 knots, and the control engineers write software to manage the associated equipment. See Figure 4 for the decomposition of the requirement. Each sub-box represents a group of engineers performing their part of the requirement. The split of work is divided and each group of engineers is responsible for meeting their part of the requirement. This is the point where systems integration gets started.

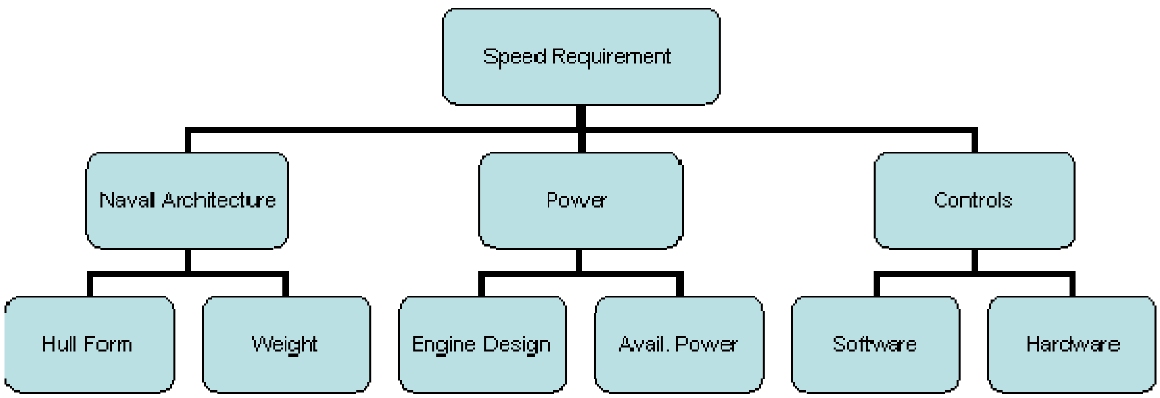

Figure 4. Example Requirement Decomposition

Does the engine the power engineers chose fit in the hull form the naval architects designed? Can production install it? Will the combination of the hull form and engine be structurally sound? Can the control system support going 30 knots within given safety parameters? None of these issues have been addressed at this stage. These and lots of other questions are addressed in the system integration sub phase when creating the design and build specifications. It is here that the constraints each engineering group put on the other groups is documented. For this reason the Department of Defense calls this sub phase "System Integration."

In Figure 5 you see the model from the left hand side or Integration part of the SDD Phase. Now we will analyze each box separately. Note that every program under the Department of Defense does not follow these steps entirely and deviation to the process as deemed necessary by the Program Office is acceptable.

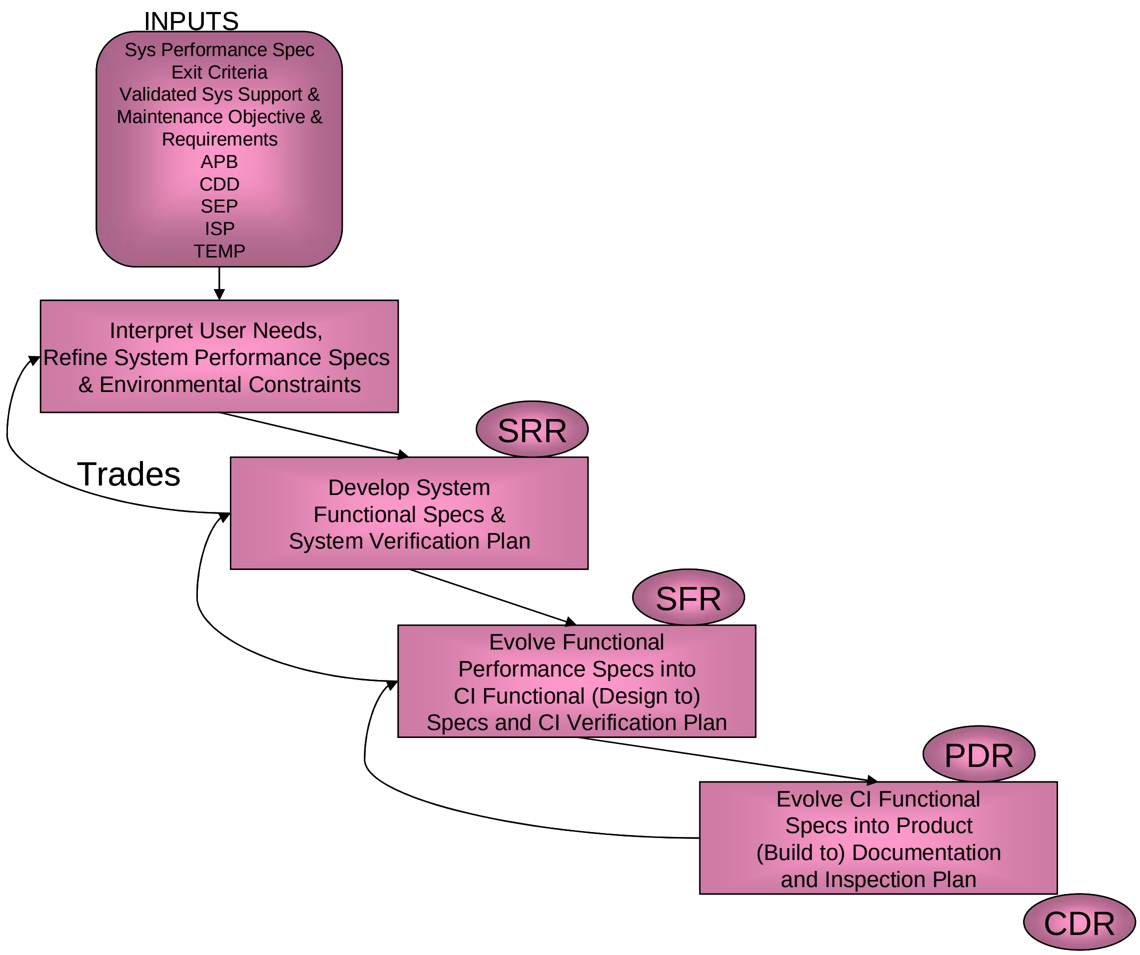

Figure 5. DoD Integration Model (after Lifecycle Model)

a. Inputs

At the completion of Milestone B you should have the documents listed below. The maturity of these documents directly affects the maturity of the system design.

- System Performance Specs

- Exit Criteria
- Validated System Support and Maintenance Objectives and Requirements
- Acquisition Program Baseline (APB)
- Capability Development Document (CDD)
- Systems Engineering Plan (SEP)
- Information Support Plan (ISP)
- Test and Evaluation Master Plan (TEMP)
- Product Support Strategy (Defense Acquisition Guidebook, 2005, Chap. 4.3.3.1)

b. Refine System Performance

From the inputs you refine the system performance. The user needs are updated and finalized as Key Performance Parameters in the Capability Development Document. Key Performance Parameters can be changed after this phase, but such change requires approval authority. The design needs to be relatively stable at this point to keep costs under control. The design spiral of developing the systems should be stopped to successfully spend the time on getting the subsystems to function together. With the release of the Capability Development Document the System Performance Specifications are updated to include the new or modified requirements. Any additional environmental constraints are addressed at this time. At the end of this phase you have your System Requirements Review. (Defense Acquisition Guidebook, 2005, Chap. 4.3.3.3.1)

c. Functional Requirements

From the updated System Performance Specification you develop System Functional Specifications and the System Verification Plan. As you do this you look back at your performance specifications and perform trade-offs between subsystems. Requirements that conflict or have the potential for exceeding cost are analyzed and changed if necessary. Here is where the integration of the subsystems begins. Interfaces between the subsystems are identified and integration requirements are developed. The System Verification Plan is developed and demonstrates how each requirement will be verified. As the requirements are added and modified the path to verification is recorded in the database with the requirement. This phase ends with the System Functional Review. (Defense Acquisition Guidebook, 2005, Chap. 4.3.3.3.2)

d. Design to Requirements

After finalizing your functional requirements you begin to create design to requirements. This set of specifications is what will be used to perform detail design of the system. The Configuration Item Verification Plan is created to show how the design requirements will be met. This phase ends with the Preliminary Design Review. (Defense Acquisition Guidebook, 2005, Chap. 4.3.3.3.3)

e. Build to Requirements

After finalizing your design to requirements you begin to create build to requirements. This set of specifications is what will be used to perform actual construction of the system. The Inspection Plan is created to show how the product will be checked against the design and build to documentation. The last review in the System Integration phase is the Critical Design Review. (Defense Acquisition Guidebook, 2005, Chap. 4.3.3.3.4)

3. Shipyard Definition of Integration

As stated earlier in this thesis is the idea that the shipyard's, or shipbuilder's, concept of integration is different than the Department of Defense's definition. This is because the two groups have different vantage points on the process. It is the Department of Defense's job to explain and document to the shipbuilder the soldiers' wants and needs. The formal requirements instantiate these wants and needs. Once the build to specifications are approved and the inspection plan is created the Department of Defense uses those documents to govern and status the progress. But for the shipbuilder only the integration planning and concepts have been defined. Integration will not take affect until production is done.

Going back to the example used in Section 2 on the power requirement we can explain the shipbuilder's point of view on integration of this requirement. As stated earlier the Department of Defense uses the definition of Systems

Integration to be when the build to specifications are completed. The shipbuilder will not know if the integration effort was successful until the ship is tested during sea trials. Therefore integration is not complete until after testing.

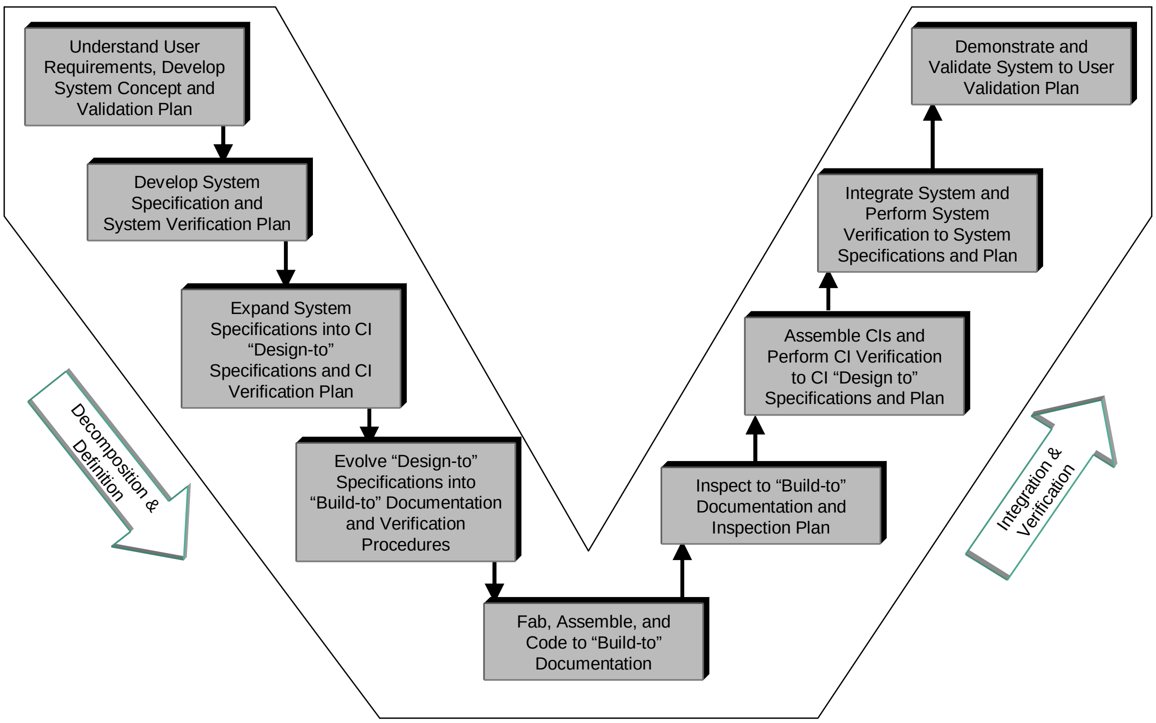

Figure 6. Basic Vee Model (from Forsberg, Mooz, and Cotterman, 2000, p. 116)

Forsberg, Mooz, and Cotterman in "Visualizing Project Management" define integration as "combining entities to prove performance and compatibly." (p.115) Proving performance and compatibly is done through testing and verification.

Figure 6 is taken from "Visualizing Project Management." The downward side, which Forsberg, Mooz, and Cotterman call "Decomposition and Definition" contains essentially the same steps discussed in the Department of Defense's model which was called Systems Integration. The upward side of the vee is labeled "Integration and Verification" by Forsberg, Mooz, and Cotterman. (p. 115) The Department of Defense calls this part of the process the System

Demonstration side. An important point here is that the Department of Defense and Forsberg, Mooz, and Cotterman are performing the same tasks in their respective models, but have different names for the steps.

Barker (2000) in “Here Be Dragons, An Integration Shopping List” defines integration as “a complex system of problems, rather than a single complex problem.” (p. 284) The Department of Defense labels Systems Integration as the planning stage for those problems, but the shipbuilder sees integration as the problems to be solved after the final stages of testing as defined by the subsystem tests.

4. Author’s Synopsis of Systems Integration Definition

Systems integration is performed to verify that the system performs as required in the System Performance Specifications. Testing is done to assure that the requirements in the build to specifications are met, but the system is not fully integrated until the performance is assured. Because there are so many different parts that pertain to just one area of performance, systems integration is a very complicated problem.

System integration takes people. A piece of software can be written to perform the task, but a person must define how the task will be performed. How the pieces fit together and work is purely a human task.

The key to systems integration is not just answering the questions you know to ask, but discovering what is not being asked! There are things that can be done to ease the integration of complex systems, but to say that if you do all of these things integration will not be a problem is impossible.

It is in everyone’s best interest to find all of the mismatches before production or operation begin. As everyone knows, fixing a design issue on paper is a lot easier and cheaper than when the system has been built. You can argue that the effort isn’t worth the trouble; you can spend lots of money working integration and not have any guarantee that the integration issues have been solved as mentioned in the paragraph above. So why even try? The reason is this: in shipbuilding real prototypes do not exist. The first of a class of ships will be used in service; ships are too expensive to build and then discard without being put into service. It is potential cost avoidance in other programs, but it's necessary in shipbuilding. This thesis is postulating that a good plan needs to be established during the requirements definition phase, what the Department of Defense calls "System Integration" to facilitate production design and construction. One the plan is developed and implemented it should be revisited and adjusted with the idea in mind to continue to reach towards meeting the performance requirements within the cost and schedule constraints. The next chapter fully presents the reasons why systems integration is more necessary now to shipbuilding than it ever has been before.

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II. IMPORTANCE OF SYSTEM INTEGRATION

A. INTRODUCTION

When making a change in the way business is done it's best to start with asking if a change is needed. This paper is proposing that a change in the shipbuilding industry is necessary to develop and build the combat ships of the future. First this chapter will describe the cost of change by using the learning curve theory. Then this chapter will explore where we are in history by comparing the differences in shipbuilding from the past to the present using two shipbuilding case studies. The comparison of these case studies will demonstrate the increasing degree of complexity with integrating a first of class ship in today's world versus the past. Next the paper will discuss a successful integrated system and a failure to demonstrate the consequences of either performing or not performing systems integration correctly.

B. LEARNING CURVE THEORY

The reality is that change comes with a price. Learning curve theory shows that you pay for change upfront. "As experience is gained with the production of a particular product, either by a single worker or by an industry as a whole, the production becomes more efficient." (Nahmias, 2000, p. 32) Shipbuilding is an industry that uses and follows the trend of learning curves. The more ships we build, the cheaper we can build them. Shipbuilders often do not plan to make money off of the first ship of the class, knowing that as their workforce becomes more experienced with the hull the cost of production will decrease. If you make a change the learning curve goes back up, and the hope is that you end up below the original learning curve. See Figure 7 for an example of what a learning curve may look like after implementing a major change.

The same can be said about the design process for building ships. Ships have been built for over 2000 years; this is not a new concept. Shipyards are filled with shipbuilders that understand the processes they use. Shipbuilding is not like designing and building anything else in the product market. Changing a shipbuilding process runs a high risk of being more expensive due to the fact of all the other changes that can snowball into that one change. It is with this knowledge and understanding that this paper lobbies for change during the detail design process.

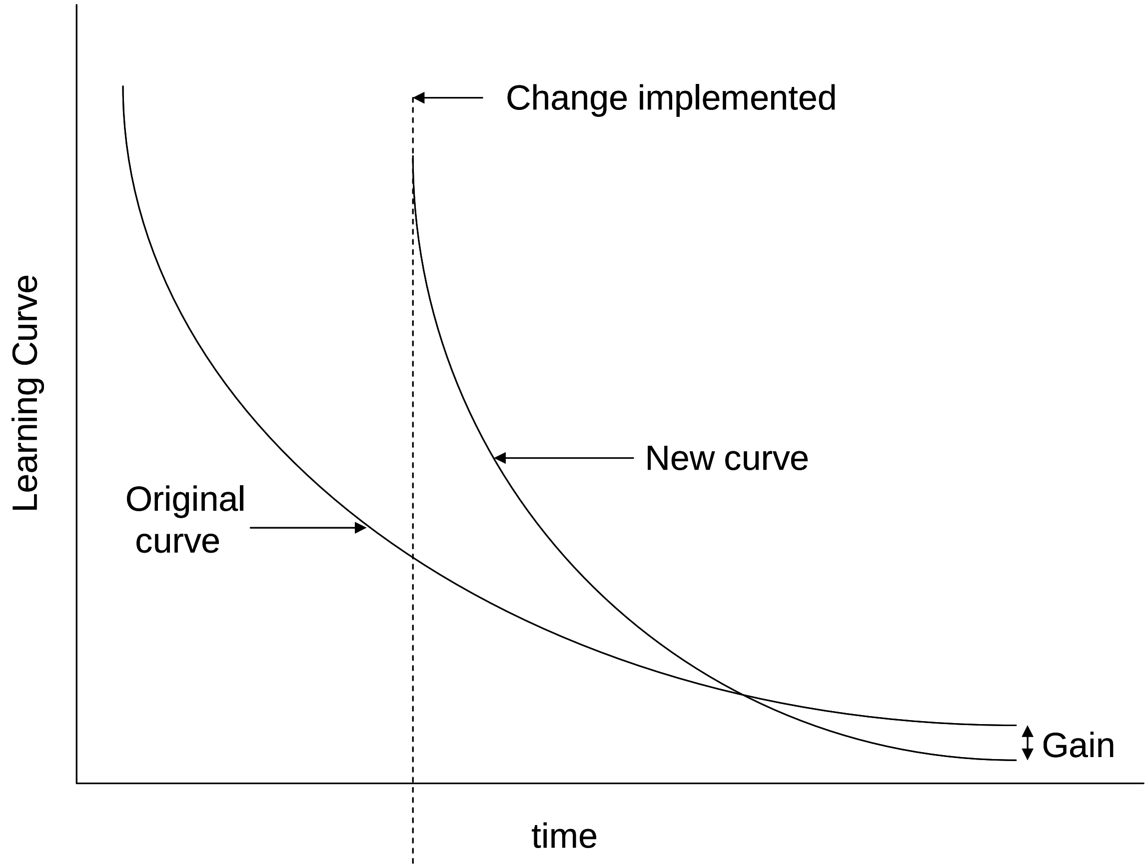

Figure 7.   Learning Curve Example

C. USS CONSTITUTION

1. Introduction

The USS Constitution is the oldest commissioned warship in the U.S. Navy. It is docked in Boston, MA and is over 200 years old. It is a wooden ship powered with sails. See Figure 8 for a picture of the existing ship. (http://www.ussconstitution.navy.mil)

Figure 8. USS Constitution (from http://www.ussconstitution.navy.mil)

2. Acquisition Strategy

At the end of the Revolutionary War United States merchants were unprotected in the ocean from pirates. During the war the country had a Continental Navy, but the cost of maintenance of even one frigate was too expensive for the moneyless nation. The last frigate was sold in 1785. (Martin, 2005, p. 11) Thomas Jefferson, then Secretary of State recommended three solutions to the pirate problem:

1. Insure cargos, ransom prisoners regularly at a fixed rate, and conduct commerce as usual,
2. Buy safe conduct with tribute, as many European nations did, or
3. Fight. (p. 12)

Congress decided that paying ransoms was cheaper than creating a navy. But eventually the overwhelming activity of the pirates caused Congress to change their mind. By 1794 Congress passed a resolution that provided a naval force sufficient to protect American merchantmen from pirates. Congress appropriated $600K for the purchase of six frigate type ships, a very optimistic price. (p. 13)

A competition was not held for the design. Joshua Humphreys was an established shipbuilder in Philadelphia and had been asked for quotes while the Secretary of Defense was gathering information on how much it would cost to build the frigates and he quite simply wanted the job and went after it. Humphreys designed a ship that was fast, powerful, heavily armored and could operate independently just about anywhere in the world. The plans for the ship were located on one sheet of paper with two views. See Figure 9. This sheet and the list of materials was all that was used to build the Navy's first frigates. (pp. 24-25)

To build the six ships six sites were chosen. Congress recognized that using one or two shipyards would reduce the cost, but they wanted to broaden the country's shipbuilding experience and hopefully procure the ships faster. The shipyards were chosen based on their experience during the Revolutionary War and politicians and businessmen's recommendations. (p. 43)

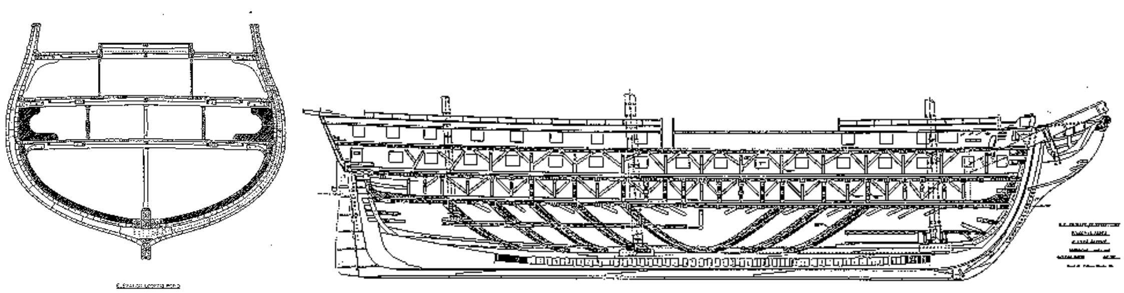

Figure 9. USS Constitution Construction Drawing (from http://www.ussconstitution.navy.mil)

Shipyards in Portsmouth (New Hampshire), Boston, New York, Philadelphia, Baltimore, and Gosport (Portsmouth), Virginia were given a contract to build the ships three weeks after President Washington signed the bill. Secretary Knox appointed four men per shipyard to oversee the construction of the frigates for the government. (Martin, 1997, p. 43)

In March 1796 an Algerine peace treaty was signed. The act that authorized the construction of the ships could be cancelled since the pirates were no longer a threat, but President Washington and Congress decided that the loss of work for all the men involved in the construction of the ships would not be in the best public interest, so it was decided to continue with the original contract but to build three ships and suspend construction on the other three. (p. 61)

With the suspension of the three ships material for those ships was sent to the ships remaining under construction. Even with the extra material approximately $100,000 of extra money was estimated to complete the three ships. This money was appropriated March 1797, an hour within the end of Washington's term for president. (p. 67)

The USS United States was the first ship launched, followed by the USS Constellation. The USS Constitution was being built in Boston and was launched last in October 1797. Anyone familiar with shipbuilding knows that the launching of the ship does not mean construction is finished. Launching of the USS Constitution was done once the ship was "ship-shape," that is a floatable vessel, but not outfitted for use. (p. 84)

By the time the USS Constitution was launched the United States was starting to see "free trade upon the high seas" affected by the "belligerents in Europe, Britain and France." Pirates were no longer the main concern. (p. 89)

In January 1798 the Secretary of War asked Congress for an additional $400,000 to finish the construction of the ships and other naval matters. (p. 89) The USS Constitution was finally ready for sea July 1798. (p. 98)

3. Cost and Schedule

It took over four years to build the USS Constitution. Initially $115,000 had been appropriated to construct the ship. The final bill was $302,719. That amounts to a cost overrun of 260%. (pp. 98-100)

The Secretary of War, McHenry, was asked to explain the cost overrun. He listed five causes:

1. Building the ships in different places
2. Size of the ships
3. Quantity of live oak used in construction

4. Rise of material and labor costs

5. Certain losses and contingences (p. 100)

The choice to build the ships at different yards certainly increased the cost, but the country needed the ships as quickly as possible. The ships were upgraded to “super frigates” from the normally armed frigates of standard construction. Live oak was used in lieu of white oak, which proved to be more difficult to procure. Labor and material costs rose. For example in Philadelphia from the date of the first estimate to launch labor increased by 40%. Then things just happened, like a fire that burned about fifty tons of hemp in Boston. (p. 100)

McHenry concluded his report with the following thought:

> The great delay that has occurred in the present undertaking must always be more or less experienced, when heavy ships of war are required to be suddenly built, and the Government not previously possessed of the necessary time and materials. It is certainly an unfit time to look for these, and prepare a navy yard, when the ships are required for actual service. . . (p. 101)

McHenry’s point is that it is not feasible to attempt to start a new shipbuilding design and construction contract at the time you need the ships. Warships require a massive amount of planning and time. But this is bound to happen when adequate resources are not available

D. DD(X)

1. Introduction

The DD(X) is the newest and most technically advanced shipbuilding program untaken by the U.S. Navy today. It is designed to be undetectable by our enemies and uses electrical drive to power and move the ship. (“DD(X),” 2005)

2. Acquisition Strategy

DD(X) was first conceptionalized as DD-21 under the Navy's vision of "Forward. . . From the Sea" in 1994. The ship was intended to replace the DD 963 and FFG 7 Classes of Destroyer and Frigate in the fleet today. ("DD-21 Zumwalt," 2000)

> The Land-Attack Destroyer (DD-21) is the first surface combatant founded entirely upon post-Cold War thinking and strategic concepts. Accordingly, the DD-21 design concept will support joint-service requirements in littoral regions. Armed with an array of land-attack weapons, DD-21 will provide sustained, offensive, distributed, and precise firepower at long ranges in support of forces ashore. With state-of-the-art information technologies, DD-21 will operate seamlessly with other naval, ground, and land-based air forces, and will be in accordance with the Navy's evolving "Network-Centric Warfare" concept of operations and IT-21 (Information Technology for the 21st Century) architecture. (http://www.metsci.com)

The Mission Need Statement (MNS) was released June 1995. ("DD-21 Zumwalt." 2000) See Figure 10 for an artistic rendering of DD 21.

Figure 10. DD 21 Artistic Render (from "DD-21 Zumwalt," 2000)

The DD 21 Program passed Milestone I January 1998 and released the formal solicitation in March 1998. DD 21 was developed under the 1996 Department of Defense Acquisition Model (See Figure 11). The first ship was to be awarded in 2004 and the Navy planned to buy 32 ship total at a rate of 3 per year. See Figure 12 for a view of the technologies planned for DD 21. The ship was expected to cost $750M per ship in FY96 dollars by the fifth constructed ship. The plan was for two teams to compete for the design and build of the DD 21 Class Ships, but both shipyards would share in the design and construction of the ships themselves with the loser being the “follow’ shipyard. Only one Systems Integrator would be selected. (“DD-21 Zumwalt,” 2000)

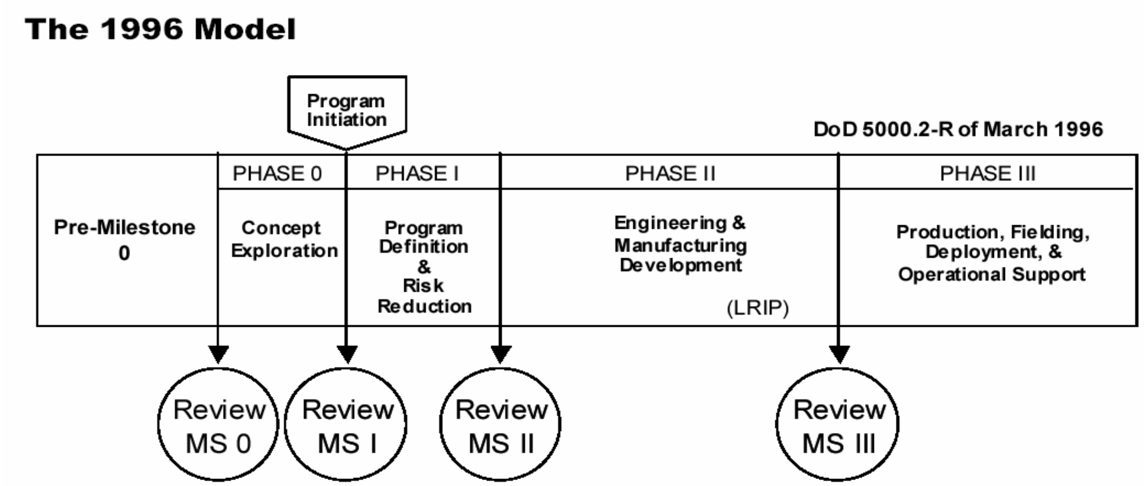

Figure 11. 1996 Defense Systems Acquisition Management Process (from Dillard, 2003, p. 29)

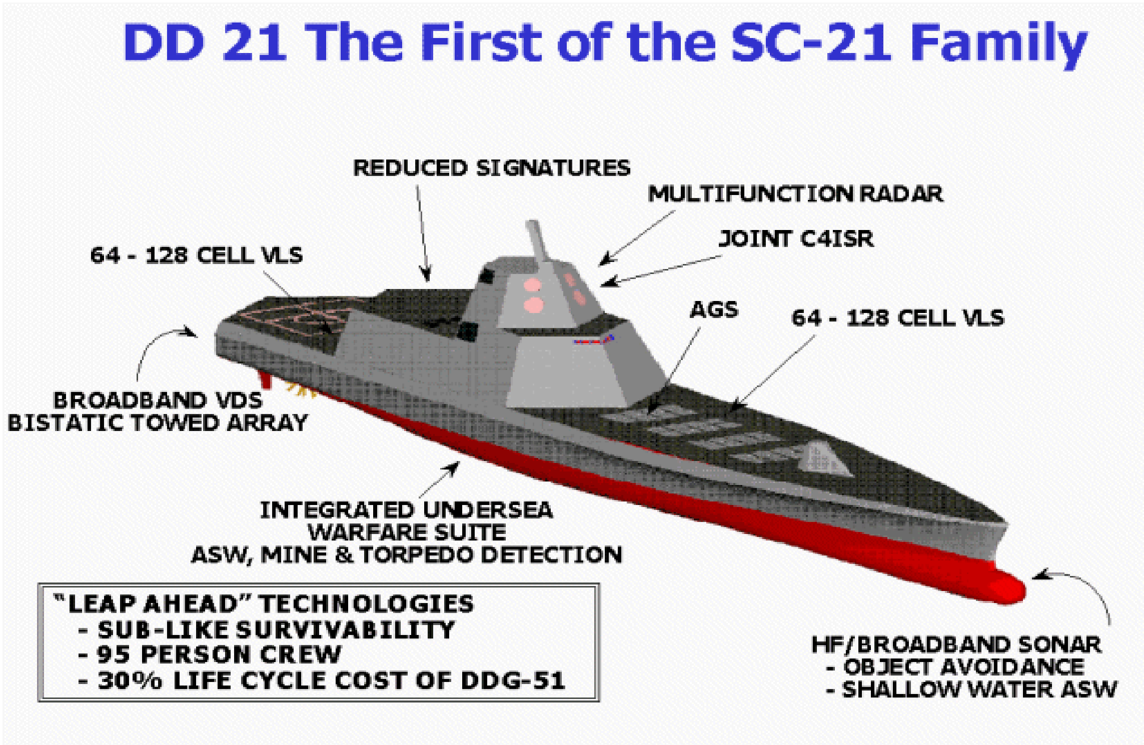

Figure 12. New Technologies of DD 21 (from "DD-21 Zumwalt," 2000)

Then the events of September 11, 2001 changed all of the military's strategic planning for the future. ("SeaPower21," 2002) In November 2001 the Department of Defense announced that the DD 21 Program had been revised and would now be known as DD(X). With the new program name the acquisition management cycle was updated to the 2000 version. (See Figure 13.) The major difference between the original cycle and the new one was the addition of the System Development and Demonstration Phase (SDD). In April 2002 the Navy awarded the DD(X) contract to Northrop Grumman and Raytheon with General Dynamics Bath Iron Works as the follow shipyard. ("DD(X)," 2005) Sea Power 21 was released later that year and DD(X)'s mission was realigned with Sea Power 21. See Figure 14 for Sea Power 21 visual. Admiral Clark wrote of the Sea Power 21 vision:

> The 21st century sets the stage for tremendous increases in naval precision, reach, and connectivity, ushering in a new era of joint operational effectiveness. Innovative concepts and technologies will integrate sea, land, air, space, and cyberspace to a greater extent

than ever before. In this unified battlespace, the sea will provide a vast maneuver area from which to project direct and decisive power around the globe. (“SeaPower21,” 2002)

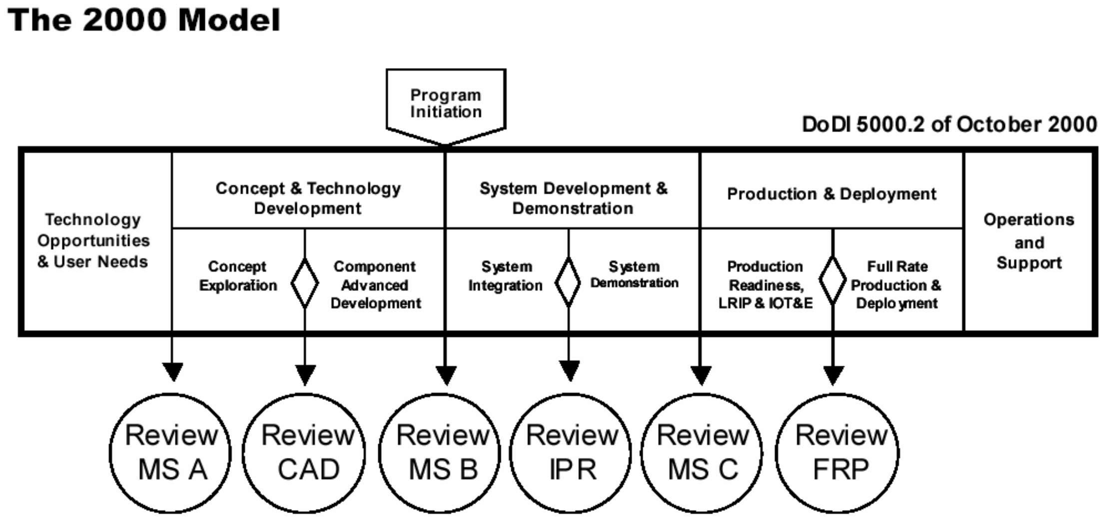

Figure 13. 2000 Defense Systems Acquisition Management Process (from Dillard, 2003, p. 31)

Figure 14. Sea Power 21 (from "SeaPower21," 2002)

The nation's military focused on terrorism, reacting to protect our homeland. Admiral Clark described the dangers as follows:

> These dangers will produce frequent crises, often with little warning of timing, size, location, or intensity. Associated threats will be varied and deadly, including weapons of mass destruction, conventional warfare, and widespread terrorism. Future enemies will attempt to deny us access to critical areas of the world, threaten vital friends and interests overseas, and even try to conduct further attacks against the American homeland. These threats will pose increasingly complex challenges to national security and future warfighting. ("SeaPower21," 2002)

In the past the nation focused on certain countries and regions as our enemies. With the events of September 11th we needed to focus more broadly across the world. ("SeaPower21," 2002)

The major changes to DD(X) included a reduction of weight. DD 21 was expected to be a 14,000 ton ship and DD(X) was reduced to 12,000 tons. Crew size for DD 21 was aimed at 95, but DD(X) increased that number. The radar system was changed from Multi-function radar to Dual Band radar. Thirty-two ships were expected to be built under DD 21, but the DD(X) Program reduced the number to anywhere from eight to twelve. First ship delivery was pushed back from 2008 to 2011. ("DD(X)," 2005) See Figure 15 for a summary of the new technologies on DD(X).

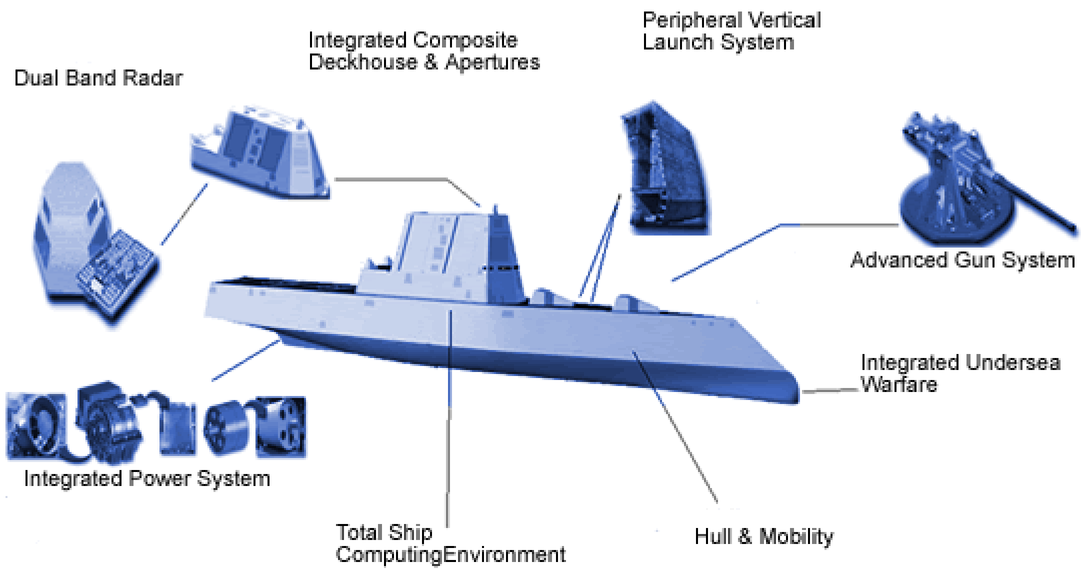

Figure 15. DD(X) New Technologies (from "DD(X)," 2005)

In February 2005 the Navy announced a change in its acquisition strategy for DD(X). This was due to the FY 2006 President's budget proposal containing only five DD(X)'s. Procurement would start in 2006 and one ship would be built each year. After months of trying to estimate the cost of the ship into the amount the Navy had appropriated for the first ship, the Navy decided to try to save some money by having the ships built at one shipyard instead of two. ("DD(X) to Go to a Single Yard?," 2005) This plan was rejected in April by Congress due to political pressure from the states of the two shipyards.

The Senate put more money than the President's Budget proposed into the DD(X) Program and the House reduced the amount of money. In June 2005 the DD(X) program had a successful 06 level Critical Design Review (CDR.) In November 2005 the Pentagon decided to allow the program to proceed into detail design and construction. The Navy currently plans to build eight ships. (Tortorano, 2005)

3. Schedule and Cost

Initially the DD21 was planned to be delivered in 2008, taking four years to construct the ship. The DD(X) is now planned to be delivered in 2012, taking six years to construct. Cost for the fifth DD 21 was aimed to be $750 M in FY 96 dollars. The latest estimate is over $3.0 B in FY 2005 dollars. (Tortorano, 2005)

E. USS CONSTITUTION VS. DD(X)

1. Introduction

The problems associated with acquisitioning ships have not changed much through the years. Both ships took longer and cost more to build than originally estimated. The mission for building the ships changed during the acquisition. Congress decides the ship's mission and acquisition strategy instead of the Navy. But as shown in Table 2 you can clearly see that the development of US Navy ships has become much more complicated.

It is obvious after laying out these facts that the DD(X) is a much more complex ship. A minimum amount of integration was needed on the USS Constitution. The design was completed by one person and was done in a reasonably short period of time. The government oversight was minimal with only four men overseeing the ship construction. But look at the crew size; twice as many sailors were needed to operate the Constitution. Technology has done a lot for us in automation and less manual work, but the complexity of having machines and software perform the tasks require more planning in the design.

	USS CONSTITUTION	DD(X)
No. of designers	1	2000
Years to develop design	1	10+
Amt of government oversight	4	200
Crew size	245	114
Number of construction drawings	1	3000+

Table 2: USS Constitution vs. DD(X) (after Martin, 1997 and “DD(X),” 2005)

All of these items add up to needing to perform more integration. As more people are involved, the design gets more complicated. As less people are used to operate the ship there becomes more interface problems by having more automated systems. Sean Barker’s (2000) definition of integration states: “Integration is a complex system of problems, rather than a single complex problem. The first difficulty with any integration project is to get a common understanding of which problems are actually being addressed by the project and which are not.” (284). Now we will analyze one system on the USS Constitution and the DD(X) to compare the complexity of the design and manpower for operability of the system.

2. Anchor Handling

All ships have an anchor of some sort. They allow the ship to stay in one place. The anchor must be heavy enough to keep the ship from moving. The USS Constitution carried six anchors and required as many as 180 men on anchor duty. The main bower anchor on the USS Constitution weighed 5304 lbs. (See Figure 16) A capstan (See Figure 17) is used to raise and lower the anchors. Twelve long poles are inserted in the capstan and ropes are used as a pulley as the men push the anchor up or down by walking around the capstan. See Figure 18 of a picture of the main bower anchor detail. It required more than 150 men to raise this anchor. (“Capstans and Anchors,” 2005)

Figure 16. Main Bower Anchor Dockside (from “Capstans and Anchors,” 2005)

Figure 17. Capstan on Gun Deck (from “Capstans and Anchors,” 2005)

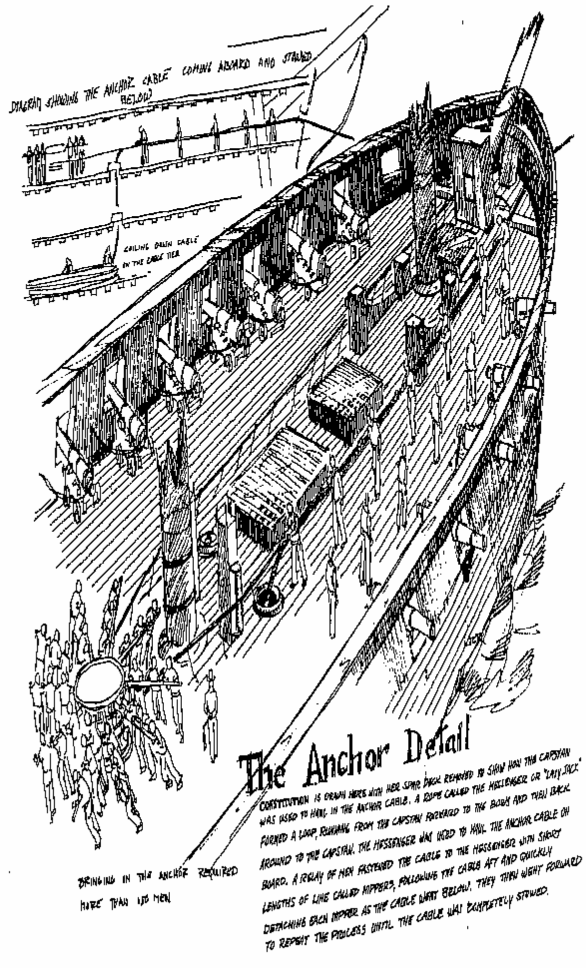

Figure 18. USS Constitution Anchor Detail (from Martin, 2005, p. 97)

There is little doubt that the system used to raise and lower the anchor on the USS Constitution is a design that worked and could be used today, but it is both labor and time intensive. The U.S. Navy is continually trying to lower what they term “life cycle cost;” that is the cost associated with operating a ship. Sailors are the most expensive part of maintaining a ship; therefore designs that reduce the amount of sailors to operate a ship are highly efficient for the U.S. Navy.

DD(X) has one anchor. The need for multiple anchors diminished with the addition of engines on ships. The DD(X) anchor system is designed as a module system. (See Figure 19) This means that the whole system can be installed in one piece and tested before it is installed. It is operated by software and requires one sailor to operate the anchor control system only when the anchor needs to be raised or lowered. It is also designed to be completely below the deck. Mechanical powered capstans are currently used on U.S. Navy ships to operate anchors, but the requirement to be hidden from the enemy from radar prevents the use of traditional capstans on the deck. This is just one example of how the DD(X) is changing traditional ship design and operation. ("DD(X)," 2005)

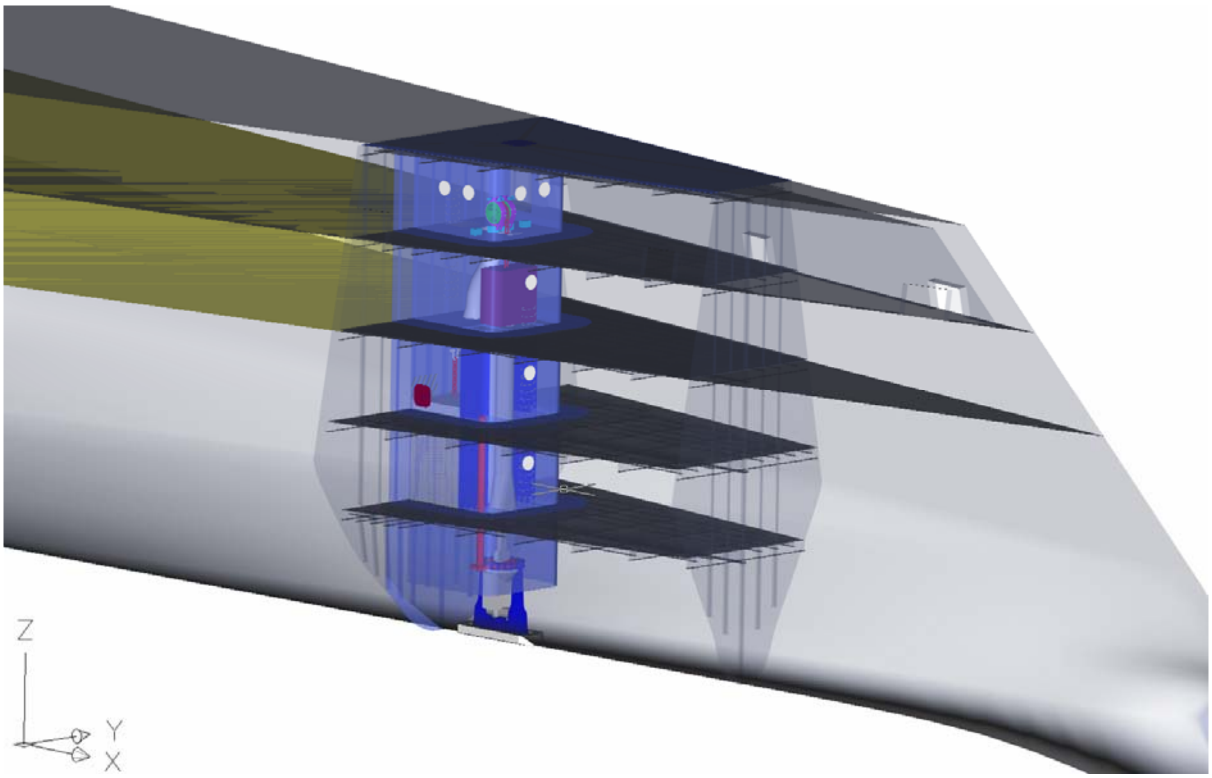

Figure 19. DD(X) Module Anchor (from "DD(X)," 2005)

The comparison of the anchor system between the two ships demonstrates how the design has gotten much more complex for essentially the same task. With the complexity comes additional benefits, most noticeable the number of people it takes to operate the anchor. On the USS Constitution up to 180 men were required to raise or lower the anchor. Only one is needed on the DD(X) and it's not even a full-time job. With the reduction of personnel comes additional design criteria and interfaces with other operating systems.

F. CASE STUDIES OF SYSTEMS INTEGRATION: SUCCESS & FAILURE

The proof that a newly developed system is integrated occurs after assembly and into operation. These two cases studies describe the success and failure of two complex systems.

1. Failure: Apollo 13

Apollo 13 launched on April 11, 1970 and was to be the third manned mission to land on the surface of the moon. On the second day of the trip from the earth to the moon, the three astronauts heard and felt a large bang when they stirred the oxygen tanks. During the next few minutes, the crew and the ground controllers determined that two of the three fuel cells in the Command Service Module had gone dead, and both oxygen tanks were rapidly losing pressure. (Howard, 1995) See Figure 20 for the damaged Apollo spacecraft.

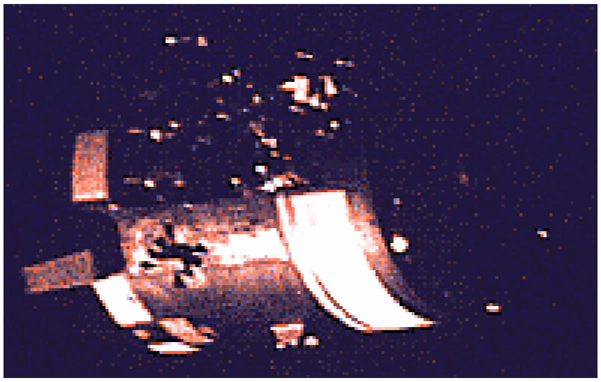

Figure 20. Apollo 13 Damaged Spacecraft (from "The Apollo 13 Accident," 2005)

The engineers at NASA did a fantastic job in bringing the crew safely home by recalculating trajectories and burn durations, devising new navigation and flight control procedures, and estimating how long critical supplies would last. Working with the crew, they developed ways to use the Lunar Module as a "life raft," using its environmental support systems, electrical batteries, and engines, to substitute for the lost capability in the Command Module. Four days later the crew returned safely to Earth, but they had been forced to abort their mission of landing on the moon. (Howard, 1995)

After two months of study, the problem was determined to have been a rupture of oxygen tank Number 2 in the Service Module. The cause, as astronaut James Lovell later wrote, was the result of an "accumulation of human errors and technical anomalies," not a single cause. (“The Apollo 13 Accident,” 2005)

The oxygen tanks had originally been designed to run off the 28 volt DC power of the Command and Service Modules. However, the tanks were designed to also run off the 65 volt DC ground power at the Kennedy Space Center. All components were upgraded to accept 65 volts except the heater thermostatic switches, which were overlooked. These switches were designed to open and turn off the heater when the tank temperature reached 80 degrees F. (“The Apollo 13,” 2000)

The Number 2 oxygen tank used in Apollo 13 had been previously installed in Apollo 10. It had been removed for modification, and in the process had been dropped about 2 inches causing noticeable damage. It was repaired and installed in Apollo 13. Tests indicated the tank was operating properly, but ground crews experienced significant difficulty draining it. But all cognizant individuals, including the flight crew, decided it was not a serious problem. (“Apollo 13,” 2000)

During pre-flight testing, tank Number 2 showed irregularities and would not empty correctly. It was decided to use the heater to "boil off" the excess oxygen, requiring 8 hours of 65 volt DC power. Because it had not been upgraded to work with 65 volt DC power this may have damaged the thermostatically controlled switches on the heater. Prior to launch, the temperature of the whole assembly rose to over 1000 degrees F, causing severe damage to the protective Teflon insulation on the electrical wires to the power fans in the tank. (“Apollo 13,” 2000)

When the power fan activated, 56 hours into the mission, the exposed fan wires shorted and the Teflon insulation caught fire. A superabundance of pure oxygen fed the fire, and the pressure rose. One oxygen tank burst, the other ruptured, and the side of the spacecraft was blown out. (“Apollo 13,” 2000)

NASA's investigation of this accident found no fundamental flaws in the Apollo design concept, but it did reveal that they needed to do a better job of system integration. They needed to improve their procedures for design review, integration of modifications, and treatment of anomalous test data. With proper interfaces developed and used during the design the accident could have been avoided. (“Apollo 13,” 2000)

2. Success: Boeing 777

In October 1990, Boeing’s 777 program was launched when United Airlines agreed to order the aircraft. In 1995 Boeing received the Collier Trophy for designing, manufacturing, and introducing into service the world’s most advance commercial jet. This was also the year that United Airlines flew their first 777 for commercial service. Since first hitting the market in 1995 Boeing has delivered over 4000 777 airplanes. The success of the aircraft is shown in its safety record and number of sales. (“Boeing 777 Program Information,” 2005) See Figure 21 for an in-flight view of the 777.

Figure 21. Boeing 777 (from “Boeing 777 Program Information,” 2005)

Boeing attributes its success of the design and manufacture of the 777 to several key things that they did differently from any other airplane development they had performed before. (“Boeing 777 Program Information,” 2005)

a. Design-Build Teams

Conduit, the program manager of the program, was quoted as saying: “If you go back to the earlier planes that Boeing built, the factory was on the bottom floor, and Engineering was on the second floor. Both Manufacturing and Engineering went back and forth. The entire Design Department was within 50 feet of each other.” (Sabbagh, 1995, p. 68) Boeing had ten thousand people working on the design of the 777. That made it impossible for everyone to be within 50 feet of each other. The Design-Build Teams were designed to allow “Manufacturing, Tooling, Planning, Engineering, Finance, and Material” to work together on the design of specific parts of the aircraft. (p. 69)

The teams met twice a week for two hours at a time. There were several logistic problems with this approach. First, people were members of more than one team, so the schedules could not overlap. Some teams had members across the country, so video teleconferencing was used. Third was finding a place to hold the meeting. The teams used an agenda and kept to the items on the agenda and careful notes were taken of the meetings. Originally Boeing had planned for 80 Design-Build Teams and ended up with 250 Design-Build Teams. (p. 70)

The Design-Build Teams enabled Boeing to do three things:

- Get it closer to right the first time before it was manufactured
- Get it closer to right before it was tested
- Test more efficiently (p. 70)

b. On Site Representation of Customers

The airline customers were brought into the Design-Build Teams if there was a specific issue they were interested in. One example is the fueling panel. United and the other airlines had fueling stands that only reached a certain height. Boeing did not consider this in their design. So Boeing moved the fuel panel closer to the ground. "I don't know what would have happened if the airplane showed up at our stations and nobody could reach the fuel panel-that would have been very embarrassing." (p. 77) By including the customer, or the user, Boeing managed to avoid design decisions that did not include the customer's needs.

c. 3-D CAD (CATIA)

CATIA was used to model every piece of the aircraft before it was built. This allowed a computer mock-up of the airplane to check for interferences between different parts of the design. "Boeing's decision to use CATIA in conjunction with a team concept emerged primarily as a means of cutting costs after analysis revealed that the predominant cost drivers were rework on the factory floor and down-stream changes." (Battershell, 1995, 217) "Every few weeks during the main CATIA design phase, a halt was called to all design activity, a design freeze. When this happened, everybody went into the system and looked for problems that had arisen because of the interfaces between one system or set of parts and another." (Sabbagh, 1995, p. 75) By bringing a halt to the design activity the interferences can be addressed one by one, not by order of precedent, but by which system needs the space. This allows the best design to be utilized, instead of a design that is just doable. In the past, "engineers were still designing when manufacturing began, and they kept making changes as problems subsequently came to light on the factory floor, on the flight line, and even in the customer's hands after the plane was delivered." (Battershell 217)

d. Simulated Testing of Systems Before Installation

"New laboratory facilities enabled the various airplane systems to be tested together as a single integrated entity in simulated flight conditions -- before the first jetliner ever took to the air." ("Boeing 777 Program Information," 2005) Because of the new systems used on this aircraft Boeing wanted the assurance that not only would the systems work, but that they would work together. This was done by simulating the conditions in the aircraft in a laboratory setting. Although this kind of testing does not reduce all interface problems, it does reduce the number of errors that would otherwise put the test team and aircraft at risk during flight testing. By testing the systems together before assembly on the aircraft, changes can be made that otherwise would be costly if the equipment was already installed. ("Boeing 777 Program Information," 2005)

The combination of these four aspects of the design and test phase of the 777 program reduced the number of modifications that in the past would have been made during manufacturing or at or after delivery. Just one of those design decisions that were made early in the design cycle could have brought failure to the entire program. Integration and design problems were fixed at the earliest possible time. The success of this program is shown in the fact that the airplane made delivery on time and the airliners have been able to use the 777 for 10 years now and are still ordering more. For this reason the Boeing 777 is a successfully integrated product.

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III. INTEGRATION CONCEPTS & IDEAS

A. INTRODUCTION

To summarize, at this point we have discussed what integration is, why integration is more important now than it has been in the past for shipbuilding, and how integration can cause the failure or success of a program. Based on this information and my experience as a shipbuilder, I present my concepts and ideas of things to do to reduce shipbuilding integration problems.

B. CONCEPTS AND IDEAS

1. Integrated Product Teams

This concept was developed by the Department of Defense from the idea of Boeing's Design-Build Teams. I have seen the use of the title in my industry, but not the concept. Currently Integrated Product Teams are just the name of the organization of a certain engineering specialty. As example of this is a Propulsion Integrated Product Team whose members include only propulsion engineers. Integrated Product Teams should include members from every part of the design, manufacture, and test that have anything to do with the specified product. As a general rule of thumb I recommend the following team members for any system being developed for a ship:

- Design engineer
- Signature engineer
- Weight engineer
- Software engineer
- System engineer
- Test engineer
- Arrangement designer
- Material buyer
- Craft discipline
- Quality inspector
- Customer

- Planner
- Cost engineer

Every Integrated Product may not need every member of this team and some will require more. You must be flexible to assure that the right people are involved.

To correctly develop Integrated Product Teams the ship should be broken down into the major systems that require the involvement of the different disciplines. This can be done based on the current management structure of engineering disciplines or craft management, but should reflect systems or products of the ship instead of stovepipes in the organization. I propose the following Integrated Product Teams as a minimum:

- Naval Architecture: The hull form needs to include ship performance in the water, but also ship performance for radar signature control.
- Power: This includes propulsion and ship's services.
- Combat Systems: Combat Systems are a set of complicated systems usually designed by a single source vendor for the shipyard. The interface of these systems requires careful planning for arrangement and weight control.
- Machinery: Machinery includes all of the equipment required to provide ship services to the crew and its associated piping. Steering gears, pumps, and HVAC are just a few examples.

Most of these Integrated Product Teams will need to be further broken down into sub-teams of the major Integrated Product Team. It then becomes the responsibility of the major team to make decisions on interfaces between the teams and the sub-teams design the actual product. Empower the sub-teams to design to performance and cost constraints by providing them goals or budgets.

If used correctly Cross Product Teams should not be necessary, because they will be members of each of the Integrated Product Teams. It is a good idea to still allow a functional management group to provide training and mentoring to the employees involved in the Integrated Product Teams by specialty.

When the teams are formed and members are chosen, give everyone a copy of each teams' organization chart. Ensure that all employees understand their role and responsibility and who they report to.

To use the Integrated Product Team approach you need to provide the necessary equipment and space to hold meetings. Have conference rooms available using a first come, first serve method for reservations with projectors, smart boards, video teleconferencing, and computers in the conference rooms. Encourage the use of video teleconferencing to reduce travel costs and employee stress. Send employees to training on how to hold a meeting and require meeting notes and action items to be recorded and tracked. Provide special training to employees working in Integrated Product Teams that use video teleconferencing.

2. Data Collection and Transfer

After you decide how the organization will be set-up, you should then determine how information will be stored and transferred. These days most communication of ideas and drawings are done electronically. At the beginning of the program you need to decide which programs will be used and ensure that when and where they interact with other programs the data can be transferred and do not change it. For example, say the whole ship model will use a 3-D CAD program such as CATIA. The structural engineers will need to perform calculations of the ship stresses. If you plan ahead and know before you buy the software to perform the stress analysis if it will use a file exported from CATIA the structural engineers will not need to re-model the ship to perform their analysis. This can save cost and time, but also accuracy as the design matures and new analyzes are performed.

3. Interface Definition

Within the Integrated Product Teams the team members will realize that it is impossible to get everyone involved with the design that they need. The HVAC system, for example, would need inputs from anyone that had a piece of equipment that required cooling. That size of team would be impossible to manage. As a management technique the teams should identify their interfaces. That is, which systems they need information from and which ones need information from them. By doing this at the beginning, once the design begins they will know and understand who they need to exchange data with.

4. Standardize Everything

All forms, presentations, reports, and tools need to be standardized. This allows the integrated product teams to focus on designing the product, instead of how to format a report. These items should be as easy to use as possible and present a clean, professional look. For example, if you need to access risk on your program, everyone should use the same tool and parameters to accurately rank a risk item. The output should be the same so that when the customer looks at the data they do not have to relearn how to read the information.

5. Modeling

Do as much modeling using computer programs as you can. The earlier that design flaws can be caught in the design cycle, the cheaper they are to change. All of the problems that will be encountered in production can not be caught by computer modeling, but the ones that can be caught earlier will save you time and money for use on those items that will be missed.

In setting up your process for modeling determine how interferences will be resolved. By freezing the design for a week or two, all the integrated product teams can focus on clearing interferences, one by one, the most optimal way possible. If the design is not frozen, the push will be on finishing the design and the interference will be resolved the easiest way possible at the time by the designer instead of utilizing the team and finding the best way.

6. Testing

There is so much cost involved with testing that if you can simulate a test on the computer first then you should do it. By doing this, you reduce the number of things that can go wrong with the test when you perform the physical test. But do not make the mistake of substituting simulation with physical testing. Just like with modeling, the computer environment can help with identifying potential problems, but a computer simulation can not take in all of the variables that occur in real life.

Test all the systems and their interactions before you install the equipment on the ship. You may not be able to completely simulate the shipboard environment, but if you can work out the majority of the bugs in the laboratory instead of aboard ship you will not impact your ship construction schedule and the environment will be easier and less costly to work in.

7. Configuration Management

Establish a good configuration management process from the beginning of the program. Make sure that all meetings, drawings, reports, are documented and under some form of configuration control. As the design matures tighten up the configuration control, but do not operate a single day on your program without it. You must be able to accurately demonstrate the reason for every design decision made for your customer or if you have a failure once the system is operational. You should plan how many drawings you will have, not just number them as they are developed. Otherwise the number of drawings will spiral out of control and will become hard to manage. Change to the design needs to be managed to assure all parties affected are aware of the change and its impact to their design.

8. Anticipate the Unknown-Unknowns

There will be problems that no one ever thought about until they see the system operating right in front of them. Realize that this will happen and plan for it. You will not be able to solve the problem if you do not know what it is, but you will be able to position the team to anticipate these types of problems and react quickly and smartly when they occur.

C. SUMMARY

By following these eight steps you will have prepared the ship for total integration. Unfortunately there is nothing that can be done to assure success, but the omission of one thing can cause failure. “The weakest link will cause your program to fail.” (Marvel, 2004)

This paper has defined what systems integration means to both the customer and the contractor, the reasons that systems integration is more important in today’s environment than the earlier years of combat shipbuilding, what happens when systems integration is done correctly and not, and finally, concepts and ideas gathered from research and experience to help ensure that a newly developed combat shipbuilding program will not fail due to a systems integration mistake. Systems integration is the single most difficult part of designing a system because until you use the system it is very hard to determine what you are not considering or leaving out of the design. A combat ship operates as a home for the sailors, the soldiers it carries, storage of equipment, a war-fighting machine, and so much more. A combat ship contains so many different systems that must be designed to work together that proper systems integration is critical for success. Only by setting up the design teams to openly communicate with the builders, testers, and users of the system will integration occur as needed to succeed. Systems integration requires people to be in contact to design the systems to interact properly.

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